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PARTICLE COLLECTION BY WATER INJECTION IN TEST CELLS

PETER S. DALEY
DIRECTORATE OF ENVIRONICS
ENVIRONMENTAL ASSESSMENT RESEARCH DIVISION

DALE A. LUNDGREN
UNIVERSITY OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL ENGINEERING SCIENCES

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This report summarizes the mechanisms by which particles may be removed when water is injected into turbine engine test cell exhaust streams. The report concludes that impaction between soot particles and droplets is the most important mechanism and that there is an optimum flow rate at which water should be injected to assure maximum removal efficiency.

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PREFACE

This report was prepared at the request of the Office of the Secretary of the Air Force to aid in understanding how water injection into turbine engine test cell exhaust streams might reduce smoke and particulate emissions. During June 1978, the Air Force Occupational and Environmental Health Laboratory measured emissions from the turbine engine test cells at McClellan AFB CA at varying water injection flow rates. Since water is normally injected into test cell exhausts to prevent structural heat damage, this procedure may provide a synergistic emission control benefit. The following discussion in conjunction with the McClellan test data may help verify this benefit. CEEDO was tasked to prepare this paper because of ongoing in-house efforts to develop test cell emission control technology. Dr Dale A. Lundgren, Professor of Environmental Engineering, University of Florida, consulted on the preparation of this document in conjunction with his related CEEDO sponsored research.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

PETER A. CROWLEY, Maj, USAF, BSC
Director of Environics

PETER S. DALEY, Maj, USAF, BSC
Chief, Env Assessment Research Div

JOSEPH S. PIZZUTO, Col, USAF, BSC
Commander

DISCUSSION

In most concrete turbine engine test cells water is injected through nozzles in the exhaust gas receiving tubes to cool the exhaust gases below concrete damaging temperatures. Generally, water injection is required only at high engine power settings because there is not enough heat at low power to cause damage. Water injection also provides some noise reduction and, under typical operating conditions, removes some particulate matter and other pollutants from the exhaust gases by entraining or absorbing them in water droplets. The droplets, because of their relatively large size collect on internal exhaust passage surfaces by impaction or settling and pass out through the drains.

Increasing the water addition rate water generally enhances particle removal by providing more droplets as collectors. The mechanisms for particle collection are much the same as those operating in conventional venturi scrubbers. Most particles are collected as they collide with droplets entering the air stream from nozzles at right angles to gas flow. At very low water flow rates, nearly all the injected water is evaporated and no particle-droplet impaction takes place. Any collection that does occur is quickly negated because the droplets evaporate and the remaining particles are carried away in the exhaust gas. As water flow increases, and more and more heat is absorbed by the evaporation of water, more and more liquid water remains in the gas stream, and collection increases.

The larger water droplets in the gas stream collect on test cell surfaces as a result of collisions or settling under gravitational forces. The collected water containing the captured particles flows down the walls and exits the cell through the floor drains. There is an optimum water flow rate for any nozzle design which creates the best water spray distribution across the exhaust stream and, therefore, most effectively "sweeps" particles from it. When the water flow is above this optimum, collection efficiency may be reduced for a variety of practical reasons greatly dependent upon the system design. For example, small droplets produced by high velocity jets cannot penetrate the exhaust stream to sweep the middle portion. Some nozzles, because of their design, may emit coherent, high velocity jets which completely traverse the stream and hence are ineffective particle collectors. Whatever the mechanism involved in a particular design, it is generally recognized that increasing the water flow rate increases collection efficiency only to an optimum point after which further water flow increases decrease efficiency.

Additional mechanisms that contribute to the removal of particulate matter by water droplets are diffusion and nucleation. Under diffusion small particles, less than approximately 0.05 μm diameter, exhibiting random Brownian motion collide with droplets and are therefore captured. If more droplets are present due to the addition of more water, the probability of collisions with droplets, and hence collection, increases.

The smaller droplets resulting from a high velocity spray (higher flow rates) present a larger total surface area for Brownian collisions and, hence, enhance collection. Because particles smaller than 0.05 μm diameter contribute little to obscuration of visible light and probably comprise less than 25 percent of the mass of the emissions from the test cell, diffusion collection is of little consequence in the case of test cell particulate emission reduction.

Particle collection by nucleation occurs when a stream containing suspended particles is supersaturated with water vapor. This supersaturation usually results from stream cooling or increases in pressure. In the case of test cell water injection, the water added vaporizes until saturation occurs. Adding additional water reduces the stream temperature and supersaturation results. The excess water in the supersaturated gas stream condenses on all available surfaces including those of suspended particles. Some of the resulting particle containing droplets collide with test cell surfaces and are therefore removed from the gas stream. Like diffusion, the efficiency of this mechanism is enhanced by the addition of more water since this leads to further cooling of the air stream and additional condensation. Venturi scrubbers employ this mechanism, but even in their case with designs optimized to take advantage of it, it is secondary to impaction in importance. In addition, test cells use a small fraction of the water required for effective venturi scrubbing. In short, nucleation is not likely to play a significant role in particle collection by water injection in test cells; however, any role it does play is enhanced by addition of more water.

CONCLUSION

In summary, inertial impaction is the dominant particle collection mechanism operating to remove soot particles from turbine engine test cell exhaust when water is injected into the exhaust stream. Diffusion and nucleation mechanisms also contribute to particle collection. All three mechanisms generally increase in effectiveness as more water is added. For impaction, however, a practical limit is reached beyond which adding more water causes decreased effectiveness. The point at which this limit is reached is a strong function of the water injection nozzle design.

TEST CELL EMISSION MEASUREMENTS IN LIGHT OF COLLECTION MECHANISMS

Emission measurements at the exhaust of a test cell should demonstrate the effectiveness of water injection in removal of emitted particulate matter. Known information on the size distribution of the emitted particles indicates that a removal efficiency of up to about 25 percent may occur. Because the water injection nozzles and other system components of existing test cells are not designed for emission control, the optimum water flow rate is unpredictable. For the same reason, results of the tests may not be indicative of the maximum degree of control that could be obtained from a system of this type.

The measurement problem itself is especially difficult because of the large size of the stack, the presence of a large amount of liquid water in the exhaust, difficulty in separation of the particulate matter contributed by the water from that contributed by the engine, inability to sample at a position where the test cell exhaust air flow is stable, and the relatively low concentration and small amount of particulate matter emitted. For these reasons, even through the injection of water into the test cell exhaust is certain to remove some particulate matter and other pollutants from the exhaust, test results verifying this removal are likely to be difficult to obtain.

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